CLAIMS

1. An apparatus for gas cluster ion beam (GCIB) mass or cluster size diagnostics for improving GCIB workpiece processing, comprising:

a vacuum vessel;

a gas cluster ion beam source within the vacuum vessel for producing a gas cluster ion beam;

an accelerator for accelerating the gas cluster ion beam along a first trajectory;

a beam deflector for controllably deflecting the gas cluster ion beam along a second trajectory, said second trajectory diverging from said first trajectory by a predetermined offset angle;

beam detection means disposed along said first trajectory at a predetermined distance, D, from said beam deflector;

workpiece holding means disposed along the second trajectory for holding a workpiece for gas cluster ion beam processing;

control means for providing deflection signals to said beam deflector for controllably deflecting the gas cluster ion beam between said first trajectory and said second trajectory;

time-of-flight measurement means for measuring the times-of-flight of components of the gas cluster ion beam over said distance, D; and

a time-of-flight analyzer to analyze said times of flight of components of the gas cluster ion beam in order to provide output information relative to GCIB mass or cluster size;

wherein said output information is used in the gas cluster ion beam processing of the workpiece.

2. The apparatus of claim 1, further comprising display means for displaying the times-of-flight of components of the gas cluster ion beam.

3. The apparatus of claim 1, further comprising display means for displaying an estimate of the size or mass distribution of cluster components of the gas cluster ion beam based upon said output information.

4. The apparatus of claim 1, further comprising system control means operably connected to said time-of-flight analyzer for receiving output information and for controlling the gas cluster ion beam processing of the workpiece.

5. The apparatus of claim 1, wherein the beam detection means comprises a faraday enclosure for collecting beam current signals.

6. The apparatus of claim 1, wherein the deflection signals comprise a beam switching signal that switches a beam pulse along said first trajectory in order to measure the times-of-flight of components of the gas cluster ion beam over said distance, D.

7. The apparatus of claim 6, wherein the accelerator accelerates the gas cluster ion beam to an energy in the range of from about 1 keV to about 50 keV.

8. The apparatus of claim 7, wherein the time duration of the beam switching signal is less than 10% of the time-of-flight for ions of size N being 500 or greater.

9. The apparatus of claim 1, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where m_i = mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ 1 = cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters.

10. The apparatus of claim 1, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters

and

$$N' = \frac{N}{q} \qquad \text{(Eqn. 3)}$$

where $q =$ cluster charge state.

11. An apparatus for gas cluster ion beam (GCIB) mass or cluster size diagnostics for improving GCIB workpiece processing, comprising:

a vacuum vessel;

a gas cluster ion beam source within the vacuum vessel for producing a gas cluster ion beam;

an accelerator for accelerating said gas cluster ion beam along a first trajectory;

a beam deflector for controllably deflecting the gas cluster ion beam along a second trajectory said second trajectory diverging from said first trajectory by a predetermined first offset angle, and for controllably deflecting the gas cluster ion beam along a third trajectory, said third trajectory diverging from said second trajectory by a predetermined second offset angle greater than said predetermined first offset angle;

beam detection means disposed along the third trajectory at a predetermined distance, D, from the beam deflector;

workpiece holding means disposed along said second trajectory for holding a workpiece for gas cluster ion beam processing;

control means for providing deflection signals for controllably deflecting the gas cluster ion beam between said second trajectory and said third trajectory;

time-of-flight measurement means for measuring the times-of-flight of components of the gas cluster ion beam over said distance, D; and

a time-of-flight analyzer to analyze said times of flight of components of the gas cluster ion beam in order to provide output information relative to GCIB mass or cluster size;

wherein said output information is used in the gas cluster ion beam processing of the workpiece.

12. The apparatus of claim 11, further comprising display means for displaying the times-of-flight of components of the gas cluster ion beam.

13. The apparatus of claim 11, further comprising display means for displaying an estimate of the size or mass distribution of cluster components of the gas cluster ion beam based upon said output information.

14. The apparatus of claim 11, further comprising system control means operably connected to said time-of-flight analyzer for receiving output information and for controlling the gas cluster ion beam processing of the workpiece.

15. The apparatus of claim 11, wherein the beam detection means comprises a faraday enclosure for collecting beam current signals.

16. The apparatus of claim 11, wherein the deflection signals comprise a beam switching signal that switches a beam pulse along said third trajectory in order to measure the times-of-flight of components of the gas cluster ion beam over said distance, D.

17. The apparatus of claim 16, wherein the accelerator accelerates the gas cluster ion beam to an energy in the range of from about 1 keV to about 50 keV.

18. The apparatus of claim 17, wherein the time duration of the beam switching signal is less than 10% of the time-of-flight for ions of size N being 500 or greater.

19. The apparatus of claim 11, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ 1 = cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters.

20. The apparatus of claim 11, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters

and

$$N' = \frac{N}{q} \qquad \text{(Eqn. 3)}$$

where $q =$ cluster charge state.

21. An apparatus for gas cluster ion beam (GCIB) mass or cluster size diagnostics for improving GCIB workpiece processing, comprising:

a vacuum vessel;

a gas cluster ion beam source within the vacuum vessel for producing a gas cluster ion beam;

an accelerator for accelerating the gas cluster ion beam along a first trajectory;

a beam deflector for controllably deflecting the gas cluster ion beam along a second trajectory, said second trajectory diverging from said first trajectory by a predetermined offset angle;

beam detection means disposed along said first trajectory at a predetermined distance, D, from said beam deflector;

control means for providing deflection signals to said beam deflector for controllably deflecting the gas cluster

ion beam between said first trajectory and said second trajectory;

time-of-flight measurement means for measuring the times-of-flight of components of the gas cluster ion beam over said distance, D; and

a time-of-flight analyzer to analyze said times of flight of components of the gas cluster ion beam in order to provide output information relative to GCIB mass or cluster size.

22. The apparatus of claim 21, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ 1 = cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters.

23. The apparatus of claim 12, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters

and

$$N' = \frac{N}{q} \qquad \text{(Eqn. 3)}$$

where $q =$ cluster charge state.

24. An apparatus for gas cluster ion beam (GCIB) mass or cluster size diagnostics for improving GCIB workpiece processing, comprising:

a vacuum vessel;

a gas cluster ion beam source within the vacuum vessel for producing a gas cluster ion beam;

an accelerator for accelerating said gas cluster ion beam along a first trajectory;

a beam deflector for controllably deflecting the gas cluster ion beam along a second trajectory said second trajectory diverging from said first trajectory by a predetermined first offset angle, and for controllably deflecting the gas cluster ion beam along a third trajectory, said third trajectory diverging from said second trajectory by a predetermined second offset angle greater than said predetermined first offset angle;

beam detection means disposed along the third trajectory at a predetermined distance, D, from the beam deflector;

control means for providing deflection signals for controllably deflecting the gas cluster ion beam between said second trajectory and said third trajectory;

time-of-flight measurement means for measuring the times-of-flight of components of the gas cluster ion beam over said distance, D; and

a time-of-flight analyzer to analyze said times of flight of components of the gas cluster ion beam in order to provide output information relative to GCIB mass or cluster size;

wherein said output information is used in the gas cluster ion beam processing of the workpiece.

25. The apparatus of claim 24, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ 1 = cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters.

26. The apparatus of claim 24, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters

and

$$N' = \frac{N}{q} \qquad \text{(Eqn. 3)}$$

where $q =$ cluster charge state.

27. A method for gas cluster ion beam (GCIB) mass or cluster size diagnostics for improving GCIB workpiece processing, comprising:

providing a gas cluster ion beam source;

producing a gas cluster ion beam with said ion beam source;

accelerating the gas cluster ion beam along a first trajectory;

controllably deflecting the gas cluster ion beam between said first trajectory and said second trajectory, said second trajectory being offset from said first trajectory by a predetermined offset angle;

defining a predetermined distance, D, along said first trajectory;

detecting the gas cluster ion beam along said first trajectory at said predetermined distance, D;

measuring the times-of-flight of components of the gas cluster ion beam over said distance, D; and

analyzing said times of flight of components of the gas cluster ion beam in order to provide output information relative to GCIB mass or cluster size.

28. The method of claim 27, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ 1 = cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters.

29. The apparatus of claim 27, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters

and

$$N' = \frac{N}{q} \qquad \text{(Eqn. 3)}$$

where $q =$ cluster charge state.

30. The method of claim 27, further comprising:
situating a workpiece in a predetermined location within said second trajectory; and
using said output information relative to GCIB mass or cluster size to improve processing the workpiece

31. A method for gas cluster ion beam (GCIB) mass or cluster size diagnostics for improving GCIB workpiece processing, comprising:
providing a gas cluster ion beam source;
producing a gas cluster ion beam with said ion beam source;
accelerating the gas cluster ion beam along a first trajectory;
controllably deflecting the gas cluster ion beam between said second trajectory and a third trajectory, said second trajectory being offset from said first trajectory by a predetermined first offset angle and said third trajectory being offset from said second trajectory by a second predetermined offset angle, said second offset angle being greater than said first offset angle;
defining a predetermined distance, D, along said third trajectory;
detecting the gas cluster ion beam along said third trajectory at said predetermined distance, D;
measuring the times-of-flight of components of the gas cluster ion beam over said distance, D; and
analyzing said times of flight of components of the gas cluster ion beam in order to provide output information relative to GCIB mass or cluster size.

32. The method of claim 31, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ 1 = cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters.

33. The apparatus of claim 31, wherein the output information relative to GCIB mass or cluster size is ascertained by the following formula:

$$m_i = \frac{2E}{v^2} = \frac{2E}{\left(\frac{D}{t_d}\right)^2} = \frac{2E(t_d)^2}{D^2} = \frac{2qeV_{ACC}(t_d)^2}{D^2} \qquad \text{(Eqn. 1)}$$

where $m_i =$ mass of ion (or cluster ion)

$E =$ GCIB energy

$v =$ velocity of ion (or cluster ion)

$D =$ ion (or cluster ion) flight distance

$t_d = t - t_0 =$ ion(or cluster ion) time of flight

$V_{ACC} =$ total beam acceleration potential

$q =$ cluster charge state

$e =$ unit charge (electronic charge)

and

$$N = \frac{m_i}{m_m} \qquad \text{(Eqn. 2)}$$

where $N =$ cluster size

$m_i =$ mass of ion (or cluster ion)

$m_m =$ mass of a molecule of the gas forming clusters

and

$$N' = \frac{N}{q} \qquad \text{(Eqn. 3)}$$

where $q =$ cluster charge state.

34. The method of claim 31, further comprising:

situating a workpiece in a predetermined location within said second trajectory; and

using said output information relative to GCIB mass or cluster size to improve processing the workpiece.